PCT

INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 6 :		(11) International Publication Number:	**WO 96/21163**
G01S 5/14	**A1**	(43) International Publication Date:	11 July 1996 (11.07.96)

(21) International Application Number: PCT/NO95/00239

(22) International Filing Date: 20 December 1995 (20.12.95)

(30) Priority Data:
944954   20 December 1994 (20.12.94)   NO

(71) Applicant (*for all designated States except US*): GECO A.S. [NO/NO]; Bjergstedveien 1, N-4000 Stavanger (NO).

(72) Inventor; and
(75) Inventor/Applicant (*for US only*): VIGEN, Erik [NO/NO]; Bergstien 21, N-3016 Drammen (NO).

(74) Agent: ONSAGERS PATENTKONTOR A/S; P.O. Box 265 Sentrum, N-0103 Oslo (NO).

(81) Designated States: AM, AT, AU, BB, BG, BR, BY, CA, CH, CN, CZ, DE, DK, EE, ES, FI, GB, GE, HU, IS, JP, KE, KG, KP, KR, KZ, LK, LR, LT, LU, LV, MD, MG, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, TJ, TM, TT, UA, UG, US, UZ, VN, ARIPO patent (KE, LS, MW, SD, SZ, UG), European patent (AT, BE, CH, DE, DK, ES, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, ML, MR, NE, SN, TD, TG).
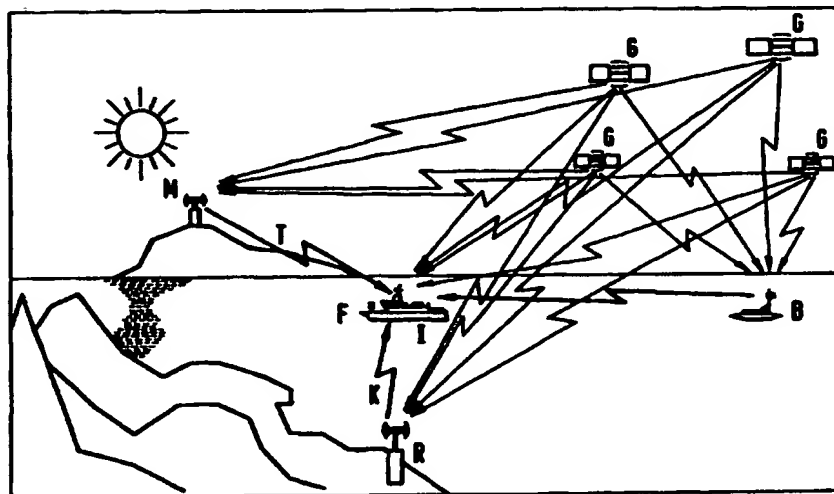
Published
With international search report.
Before the expiration of the time limit for amending the claims and to be republished in the event of the receipt of amendments.
In English translation (filed in Norwegian).

(54) Title: A METHOD FOR INTEGRITY MONITORING IN POSITION DETERMINATION

(57) Abstract

In a method for integrity monitoring in position determination by means of the Global Positioning System (GPS), especially by means of differential GPS (DGPS) or multi-station DGPS, wherein there is employed a monitor station (M) with a first GPS receiver, provided at a location with a known geographical position, GPS-based position measurement results are transferred on a communication line from the monitor station (M) to a user location (F) the integrity of whose geographical position has to be monitored by means of a second GPS receiver provided at the location (F). A space vector between the location of the monitor station (M) and the location (F) is determined by means of the position measurement results for the location (F) and the monitor station (M), whereupon the degree of agreement is determined between the position for the location (F), the space vector and the known position of the monitor station (M), the degree of agreement being required to correspond to a maximum error in the position for the user location (F).

1

A method for integrity monitoring in position determination

The invention concerns a method for integrity monitoring in position determination by means of the Global Positioning System (GPS), especially by means of differential GPS (DGPS) or multi-station DGPS, wherein a monitor

5   station is employed with a first GPS receiver provided at a location with a known geographical position.

It is normally desirable to have a high degree of certainty that a navigation aid really provides a performance which lies within the expected range of accuracy. A standard method is to employ a surplus of measurements in order

10   to verify this, e.g. by means of statistic test methods. When using GPS this excess is dependent on the number of satellites which are visible to the user at any time, which at times means that the control of surplus measurements is reduced. The typical navigation user will have to compensate for this by employing greater safety margins which can lead to disadvantages and

15   increased costs.

In the context of entrepreneur activity where fixed measured points do not exist within reasonable proximity such as offshore, for activities such as, e.g., the acquisition of seismic data or pipe laying, it will be of great economic importance to be able to verify the reliability of the positioning system within

20   the same tolerance independent of the number of available satellites.

A method is proposed herein which will make this kind of integrity monitoring possible.

At present GPS is in the process of developing into a universal navigation system for use onshore, at sea and in the air. The system is owned by the US

25   authorities and is placed at the disposal of all users who acquire a GPS receiver. The system is therefore very inexpensive for the user. Moreover the system has a global coverage which is quite unique in comparison with previous systems, while at the same time it offers the possibility of performing extremely accurate position determination.

30   GPS will therefore be the natural choice of navigation system in the future for most people who require to navigate.

It is highly desirable that the necessary control of the GPS application can be verified without incorporating extra systems since these will usually have a limited range of coverage as well as increasing the costs and thereby losing many of the advantages of using GPS.

5   A typical demanding application of GPS position determination is in connection with the acquisition of marine seismic data. In this field so-called differential GPS is used in which correction data is broadcast from measuring stations located at known points. By utilizing these corrections the accuracy can be substantially improved and this kind of application is typical for
10   accuracy requirements in the range 0.5 - 10 metres. In seismic data acquisition it is also normal practice to have buoys deployed in the water and these may also by towed by a vessel. The position of the buoys is also required to be known with a high degree of accuracy, and GPS is also a suitable system for performing such a determination. In this case a relative
15   determination is made between, e.g., the boat and the buoy concerned.

The fact that both a high degree of accuracy is required here and simultaneously a high degree of certainty that the actual performance should agree with the estimated or expected performance makes integrity monitoring extremely demanding. There is a requirement that errors which are not
20   appreciably greater than the noise in the system should be detected and rendered harmless. The economic risk involved in faulty positioning of geological information and constructions is formidable. The proposed method will be an aid to solving this problem.

The use of a navigation system will always be encumbered with errors. The
25   coincidental errors, i.e. random noise, are relatively harmless in this connection. The level of this noise is generally used to describe the accuracy of a system, and in the case of GPS the level of this noise is low. Such errors are easily dealt with by recognized calculation algorithms based on the least squares method or Kalman filtering.

30   Since the noise level in GPS is low the error picture is dominated to a greater extent than for many other systems by model errors which usually take a systematic course. Systematic errors of this kind can have a very unfortunate effect on the position determination performed by algorithms of the above-mentioned type. Great emphasis is therefore placed on detecting and

removing such errors prior to the position determination. Model errors should be understood here to mean deviations between the mathematic model, on which the performance is based, and the real physical conditions which prevail during use.

5   GPS is a comprehensive system and the possible sources of error are there-fore also many. The system is often considered on the basis of 3 main components:

*   a space segment, i.e. satellites

*   a control segment, i.e. ground stations and control centres which are
10   responsible for daily operation of satellites and signals

*   a user segment, i.e. the user's receiver system with antenna and software.

Errors can occur in the space segment in connection with, e.g., power supply, antennae, clocks, stability, etc. Such conditions will normally result in the satellite becoming unusable rather than introducing small errors which the
15   user has trouble in detecting. The control segment monitors the satellites with regard to such errors and by using the satellite signals will warn the user about the condition. Of course it cannot be ruled out that an error with relatively little effect can occur here, with the result that the warning to the user arrives too late or not at all. The reporting mechanism which is
20   employed can also cause it to take many minutes, and perhaps as much as an hour, between the detection of the error and notification of the users.

In addition to monitoring of the satellites the control segment will perform measurements which will form the basis for calculating updated satellite orbits and clock operation. These data are programmed into each individual
25   satellite of the control segment. There are, of course, many details which potentially can go wrong during this process, e.g. operator error, software error, error in connection with uploading of data and programmes to the satellites, measurement error on the ground stations as well as during transfer of these data to the control centre etc. The control segment works under
30   stringent requirements with regard to procedures with continuous quality improvement. Even though it cannot be ruled out that errors can also occur in

4

this part of the process it is probably not the most conspicuous source of error.

In the user segment on the other hand the possibilities for error are many and the possibilities for detecting them correspondingly limited. Examples of errors which may arise are as follows:

*   receiver error

*   software error

*   measurement error as a result of phase error on account of multiple-path interference

*   deviation in signal path as a result of ionospheric and tropospheric refraction.

If differential GPS is employed the effects will also be felt of corresponding errors in the reference stations which are in use and the transfer of correction data therefrom.

The first three types of error are cumulative, while the last is reduced to some extent by the fact that the error is common to the reference stations and the user, but this will be dependent on the distance between them.

Thus it is the duty of the user to protect himself against any remaining errors from the space segment and the control segment in addition to the user segment-oriented error sources. In the case of differential use combatting the so-called "Selective Availability" (SA) will also take a similar form to the normal error sources. Intentional errors are built into SA in GPS in order to prevent unauthorized users from achieving ultimate accuracy. The unauthorized user naturally obtains no information on what the errors are, but information is supplied on what he can expect. The integrity control in relation to this will thereby take the form of an investigation into whether one is more influenced by SA than by "what can be expected".

To sum up briefly it can be said that if the user does not check the system in relation to these and other possible error sources he does not know what

5

performance it gives, and the result is that he is using an unreliable
navigation system. The conscientious user must therefore have a method
available in order to perform such a check.

The most common method for integrity monitoring is based on the use of
statistical hypothesis testing. The initial hypothesis selected is normally that
all measurements are distributed according to a known statistical distribution,
usually normal distribution. It is then tested against a number of alternative
hypotheses, in each of which there is assumed a specific error pattern.
Standard alternative hypotheses are the occurrence of only one error at a time
which leads to testing of as many alternative hypotheses as there are
measurements.

The weaknesses of the method consist in the fact that if the error pattern
which actually occurs in a given error situation does not form part of any of
the alternative hypotheses, it is not certain that the error can be detected.
Moreover it is a purely statistical method where a given error only has a
probability of being detected and identified. In other words there is also a
certain probability that an error will avoid detection. These probabilities are
influenced to a great extent by the ratio between measuring accuracy and the
size of the error against which protection is required. The method begins to
be highly impractical for most applications when the ratio approaches 1:5, but
there is no absolute limit. This practical limit is in turn very dependent on
geometrical strength in the position determination, since the poorer the
geometry the less the probability of detecting a given error.

The principle is based on control of the agreement of the measurements. If
there is only one surplus measurement it will only be possible to detect that
one error exists, but it is impossible to isolate it by means of this method.
Thus it also becomes clear that if there is no surplus measurement, the entire
agreement will become meaningless and errors cannot be detected.

The problem with an insufficient surplus of measurements or poor geometry
can be remedied by combining GPS with other systems.

GLONASS is a Russian satellite navigation system which works on the same
principle as GPS. This will double the number of satellites available and is
thereby expected to remedy this detail. The drawbacks with this method are

associated in the short term with the availability of receiver equipment for GLONASS signals. Present day receivers are expensive compared with GPS receivers. In the longer term there is a degree of uncertainty with regard to the availability of GLONASS signals.

5   INMARSAT is in the process of launching new versions of its communication satellites. These have an inbuilt function enabling them to transmit signals in approximate GPS format. These signals will carry additional information concerning the condition of the GPS satellites, but are also intended to be used to make additional measurements, and thus the effect will
10   be the same as if there were an extra GPS satellite available. This will make 1-3 extra measurements available, thus ensuring a higher minimum number of measurements. The disadvantage is that these signals are not yet available. Moreover it is worth noting that the satellites travel in geostationary orbits, which leads to a gradual deterioration in the coverage at higher latitudes and
15   it becomes unavailable in the Arctic and Antarctic. Signals from satellites with a low angle of elevation are generally of poor quality due to the effects of refraction. Another phenomenon which can occur due to the fact that all these satellites lie on the same plane is that if the available GPS satellites should also happen to lie close to the same plane, the extra measurements
20   will not provide any significant contribution to the geometry.

Inertial navigation systems will also contribute with additional measurements, but of a different kind. These systems are not sensitive to fixed or slowly varying position errors, and are therefore unable to assist in exposing them. Moreover there is a substantial cost consideration to be taken into account
25   when using inertial platforms.

The above methods have the advantage that they all focus on the integrity of the user's position estimate which is the important factor in this context, but it can be problematic to strike a suitable balance between low probability of false alarm and high probability of detection. Low probability of false alarm
30   also affords low probability of detection and vice versa.

By providing a GPS receiver at a known point it will be possible to express with much more certainty the reliability of the system, and any errors can be demonstrated with a greater degree of certainty. This is a recognized principle for a so-called monitor station. If an application of differential GPS requires

to be checked, this station can be supplied with the same differential corrections as the user receives. As long as this monitor determines its own position with a degree of error which is less than that against which protection is desired, it will be assumed that there is no error in the system. As

5   soon as the error limit is exceeded the monitor will transmit a warning to the user via a communication channel suited to the purpose. This can often be arranged in such a manner that the warning is transmitted to the closest reference station which then passes it on to the user together with the broadcast of differential corrections. The user will thereby be able to receive the

10   warning within a few seconds.

However, this system has a substantial weakness in that the user's own measurements do not form part of the control. As indicated in the introduction it is at this point that there is the greatest probability of errors occurring.

15   The object of the invention is to provide a method which eliminates the disadvantages of known methods of integrity monitoring, this object being achieved by transferring GPS-based position measuring results on a communication line from the monitor station to a user location whose integrity will be monitored by means of a second GPS receiver provided at the

20   location, to determine a space vector between the location of the monitor station and the location by means of the position measuring result for the location and the known position of the monitor station, and to determine the degree of agreement between the position of the location, the space vector and the known position of the monitor station, the degree of agreement being

25   required to correspond to a maximum error in the position of the user location.

It is proposed to employ a GPS receiver positioned at a known point in the same manner as for the position monitor described above, but the measurements which this performs are used in a different way.

30   It is recommended that integrity monitoring by means of hypothesis testing should always be used, since the only drawback this entails is that sufficient calculating power must be made available in order to perform the calculations continuously. The proposed method will constitute a more stringent extra

control, and its greatest importance will naturally lie in filling in the gaps in the first method.

Quite simply, the method is based on the fact that the monitor station transmits its measurement results to the user via a communication line suited to the purpose. The user can then combine these measurements with his own in order to determine a space vector between himself and the monitor station. The user will then be able to check that there is agreement between his own position, which requires to be controlled, the determined space vector and the monitor's known position. The user has previous knowledge of the monitor's exact position. The discrepancy which can be tolerated can be set as being equal to the position error against which protection is desired. The position gap can be determined by means of a simple solid geometric observation or by geodetic calculations.

The method is particularly well suited to a vessel for marine seismic data acquisition which also uses GPS as a navigation aid. This will be shown in the following description, but the method is not restricted to this area of application. This special application, however, is the basis for the further detailed description.

The invention will now be explained in more detail with reference to the drawing, wherein fig. 1 illustrates a relevant navigation situation with position determination, and fig. 2 an example of the siting of a monitor station in relation to user location and one or more reference stations.

Fig. 1 illustrates how a vessel F navigates by means of signals from GPS satellites G combined with differential corrections broadcast via a broadcasting medium K from one or more reference stations R which are arranged in known position(s). The vessel F which is equipped with a GPS receiver together with a receiver for the broadcasts from the reference station(s) R performs the navigation by means of so-called differential GPS (DGPS) which is a known method.

The vessel F tows one or more buoys B whose position is determined relative to the vessel F by a suitable GPS-based technique. For this purpose the buoy(s) B is equipped with a GPS receiver and the equipment required for telemetering measurement data for the vessel F.

As shown in fig 1, a GPS receiver has been provided in a monitor station M at a co-ordinate-determined point. In addition the monitor is equipped with the necessary equipment for communicating via a suitable medium T with the vessel F. It is also desirable for the vessel F to be equipped with an extra

5   GPS receiver in a secondary measuring station I on board. The reason for this is described below in connection with the method.

The vessel determines its own position by means of signals from the satellites G and the reference station(s) R according to the method for differential GPS (DGPS). The space vector from the vessel F to (each of) the buoy(s) B is

10   determined by means of the same signals from the satellites G observed from F and from B. The measurement results from the observation of the signals on board B are transferred to F through the established telemetry channel. Both sets of measurements are transferred to a computer on board the vessel F. The measurement differences between F and B for the same satellites

15   provide a data set which indicates distance and clock error differences between F and B in relation to each of the satellites G concerned. On the basis of known GPS technique it is then a commonplace task to derive the space vector and the clock difference between F and B.

The problem now is how the integrity of this position determination can be

20   monitored if none of the known methods mentioned above is adequate. First and foremost the problem is relevant to the position determination of F since

*   the use of buoys is restricted to special operations such as seismic data acquisition;

*   in the case of seismic data acquisition the integrity of the buoy(s) will

25   also be controlled by means of other necessary (underwater) positioning systems such as, e.g., hydroacoustic measurements and magnetic com-passes.

The integrity monitoring of the position determination for F can be performed by transferring measurements from the monitor station M to the vessel F by

30   means of the communication connection T. The information which is trans-mitted from M to F is of exactly the same type as that which is normally transmitted from B to F. The measurements F received from M are entered into the same computer as mentioned above. Thereupon exactly the same

calculation is performed for the monitor M as that which is performed for the buoy(s) B. This means that a space vector is determined between F and M. If all measurements, differential corrections, data transfers, calculation models and software programmes are correct, the vessel's F position together with the space vector will be able to generate a position for the monitor M which agrees with the previously known coordinates for M. This position can be calculated by means of a solid geometric observation or by a geodetic calculation.

It should be noted here that the determination of the space vector between F and M is performed completely independently of the reference station(s)' R measurements and its (their) calculated differential corrections. A complete control is thereby obtained of the DGPS infrastructure as it appears to the user. This is a distinct improvement in relation to the above-mentioned position monitor which is installed at a different location from the user and operates under independent conditions. The proposed method does not appear to have any weaknesses in relation to the prior art.

There is, however, a weakness in relation to the problem of monitoring the integrity of the vessel's F position. Theoretically it is quite possible to generate a correct position for M according to the described method even though the position for F has a moderate error. This situation can arise if there is a measurement error in the observation of the satellite signals from the satellites G on board F. These measurements are used both to obtain the position for F and to determine the space vector between F and M. On closer consideration it will be revealed that these two elements will be encumbered with equally substantial errors from any measurement error of this kind. The effect on position and space vector respectively will have opposite signs, thereby cancelling the error when the position for M is derived. However, this problem is easily remedied by arranging an additional GPS receiver I on board F. Duplication of the receiver and antenna system will provide direct protection against errors in this equipment, but if the antennae are located at a distance from each other which is sufficient to achieve reasonably indepen-dent observation conditions (e.g. 5 metres or more), this will also provide an efficient protection against multiple-path interference which is considered to be the most frequently occurring source of error for a GPS user. Like the measurement from M the measurements performed by I are entered into the computer, and a space vector is calculated in a similar fashion. This space

11

vector can then be compared with the known vector which can be measured between the antennae on board by other means, e.g. by a tape measure and use of the vessel's F navigation compass.

One of the greatest sources of error in connection with DGPS is refraction of the GPS signals through the ionosphere. The variations in this effect are great enough to introduce substantial errors in relation to generally known models of this effect. Potentially this could lead to an integrity problem if there are stringent requirements. The simplest way of avoiding this is to use two-frequency GPS equipment. Equipment of this kind is much more expensive for the user. Moreover all publicly available reference station services of any extent are based only on single-frequency equipment, thus eliminating much of the benefit. There is of course nothing to prevent both the monitor station M and the vessel F from being equipped with two-frequency equipment, thus permitting a more accurate vector to be determined virtually unaffected by ionospheric errors. In this case an even more efficient integrity monitoring would be achieved. However, another proposal is presented here which enables this increase in costs to be avoided.

The influence of the ionosphere on the GPS signals is correlated over relatively great distances (>1000 km). This is exploited to the advantage of DGPS as any remaining errors are largely cancelled between reference station and user. However, it is the integrity of this detail which has to be monitored since it is based on a statistical assumption. By positioning the monitor station M in relation to the user F and the reference station(s) R in such a manner that the distances F - M and F - R are less than M - R, the advantage is achieved that the expected correlation between F and M is greater than between R and M. This fact makes the vector F - M suitable for checking the accuracy of the ratio between R and F. See fig. 2 of the drawing.

The chosen position of the monitor M in relation to the reference station R provides a favourable operational area for the vessel F which is defined by the two circular arcs with centres in the points M and R respectively and with radius equal to the distance between M and R.

If a network of reference stations R is employed, in order to make optimum use of DGPS with regard to accuracy it will normally be desirable to arrange the reference stations R in a circle around the operational area for the vessel

12

F. Unless the extent of the network of R is extremely large (e.g. considerably larger than 1000 km), ionospheric refraction will no longer be a great threat. In the case of such a network of R, within which F operates, and regardless of size, the optimum position for M will be located within the same network, but then the condition illustrated above naturally cannot be fulfilled for all reference stations at the same time. On the basis of a pure consideration of integrity it will be best to have M as close to F as possible, but this is not really critical.

The best way of performing the control is to have the position of the monitor station continuously estimated by the computer which also compares the estimate with the known coordinates. In its simplest form it can be performed in such a manner that the computer transmits an alarm to the user when a predetermined limit for position error is exceeded. It should thereby be possible to expose errors which are less significant than those detected by utilizing the statistic hypothesis testing alone.

Nor is there any reason why the method of hypothesis testing should not be extended to also help to find the error source after a significant error vector has been detected by means of the monitor's measurement data. The actual hypothesis formulation will then have to be modified in order to utilize the knowledge obtained by including the monitor, but the object will be the same, viz. to find the most probable error measurement in order to remove it. A major advantage of this method in relation to that described above is that identification is possible even though the vessel F does not have access to any surplus measurements apart from those the monitor has performed. A natural consequence if F is already operating with a minimum number of measurements is that it is only possible to expose and correct the error in the measurement value, but there is then no longer a sufficient number of correct measurements to generate a correct position.

Depending on the kind of communication connection which exists between the monitor M and the vessel F, there are at all events two strategies to choose between for the use of integrity monitoring according to this method. In the case of a relatively expensive connection, its use can be limited to those periods where alternative methods do not work satisfactorily. A second strategy can be to perform random sampling for short periods. An alternative method which can be recommended if it is not too expensive, is to maintain

continuous connection with the monitor, thus making full use of the integrity monitoring according to this best method.

It will presumably be natural to utilize the GPS receiver I all the time since it is installed in any case, and no additional costs are incurred when it is used. This will provide protection against multiple-path interference which, as already mentioned, is a frequently occurring source of error.

If the position determination has to be referred to a different datum than that which, e.g., GPS employs, it will be necessary to perform a datum transformation. By means of the method according to the invention the integrity of the datum transformation can be monitored. Otherwise it is generally extremely difficult to verify a datum transformation, leading to one of the most frequently occurring navigational errors in present day use of satellite-based navigation. By employing integrity monitoring according to the present invention, therefore, navigational errors during datum transformation can be eliminated independently of which datum the transformation is based on and of which datum reference is desired.

The method has a number of advantages, some of which are most pronounced in connection with marine seismic operations or the like.

• The "integrity gaps" which exist in previously known methods can be filled.

• The integrity monitoring becomes more complete due to the fact that the user's system is a necessary and integral element of the method. In other words, all known and perceived errors and error effects of importance for the application are monitored.

• The monitoring is carried out on board where the user has access to all the material used in the control.

• Since the user's ordinary software for position calculation and space vector calculation is employed as the central elements in the integrity control, an additional benefit is obtained in that this software is verified simultaneously. This is of great practical importance for marine seismic

operations where there is often a requirement for such verification before
the vessel leaves port.

* The method is flexible with regard to choice of communication method T
  between the monitor M and the vessel F.

5   Since the monitor M in principle performs the same operation as the buoy(s)
B it is an extra "bonus" to be able to use the same receiver unit. Such a unit
is developed to be capable of operating on a buoy over a substantial period
without intervention from any operator, and it can be remotely operated to a
certain extent. By using the same type of unit a standardization of the

10   equipment is achieved which simplifies use, and it also has the advantage that
any integrity problems are exposed with this unit which is used for all space
vector determination in the system.

It will be advantageous to couple a modem to the unit located in the monitor
station M. This makes the communication with M from the vessel F very

15   flexible, since any telephone connection of reasonable quality can be used.
Thus a vessel in port or near the coast can use mobile telephone connection
as a reasonable communication method. Beyond this range communication via
INMARSAT can be employed. This is of course an expensive connection,
and it can be desirable to restrict the use to those periods when it is strictly

20   necessary. It will be possible for some seismic vessels to have fixed tele-
phone lines to shore through NORSAT B satellite communication or the like.
If such lines have available capacity this will naturally permit the integrity
monitoring to be implemented in a very reasonable fashion.

If more than one vessel has to be capable of utilizing the monitor simul-

25   taneously it will be desirable to couple up more modems to the receiver unit
in the monitor station. This can be done by splitting the RS232 line from the
receiver unit to the modem and distributing it to more modems which then
can each have its own telephone line. Standard equipment exists for per-
forming this task.

30   The method is flexible with regard to the position of the monitor station M. It
will therefore be possible to choose a location where the costs of installation
are minimal. This may, e.g., be at an operations office within, e.g., a distance
of 1000 km from the vessel's F operational area. Other examples of where

electricity and telephone lines are conveniently accessible may be hotels in large towns if operations are being conducted in distant locations.

It should be understood that the method according to the invention can be used with other communication methods and concepts than those described here. The vessel's measurements can instead be transferred to the monitor station which then performs the analysis. Otherwise all the data can be transferred to a central location where the analysis is performed. Other positions and/or vectors can be calculated on the basis of similar measurement stations for comparison and control. Nor is it necessary for the vessel to navigate by means of GPS or DGPS, as other navigation systems can be employed for position determination. The method according to the invention can also be employed in other connections than marine seismic exploration, for navigation on land or in the air, and with modifications for more than one monitor station. Moreover the method can also be employed in a similar manner for GLONASS and/or other similar navigation systems. Thus it should be understood that the above-mentioned and other applications which will be obvious to a person skilled in the art, are considered to fall within the spirit and scope of the invention.

Implementation of such an integrity monitoring system will make low-cost GPS navigation available for many applications where the integrity requirements have been too great for GPS otherwise to have been acceptable. Examples which can be mentioned are marine seismic data acquisition, critical operations offshore, aircraft navigation, particularly in connection with approach and landing, navigation of aircraft during taxiing and harbour navigation for boats.

PATENT CLAIMS

1. A method for integrity monitoring in position determination by means of Global Positioning System (GPS), especially by means of differential GPS (DGPS) or multi-station DGPS, wherein there is employed a monitor station (M) with a first GPS receiver, provided at a location with a known geographical position,
characterized by transferring of GPS-based position measurement results on a communication line from the monitor station (M) to a user location (F) the integrity of whose geographical position has to be monitored by means of a second GPS receiver provided at the location (F), determining of a space vector between the location of the monitor station (M) and the location (F) by means of the position measurement results for the location (F) and the monitor station (M), and determining of the degree of agreement between the position of the location (F), the space vector and the known position of the monitor station (M), the degree of agreement being required to correspond to a maximum error in the position for the user location (F).

2. A method according to claim 1,
characterized in that the absolute value of the position error is determined by means of solid geometric or geodetic calculations.

3. A method according to claim 2,
characterized in that the position of the user location (F) is determined by means of GPS signals and differential correction signals transferred from one or more reference stations (R) in a known position or known positions.

4. A method according to claim 3,
characterized in that the differential corrections from the reference station or reference stations (R) are received by a receiver provided for this purpose at the user location (F).

5. A method according to claim 4,
characterized in that there is provided an additional GPS receiver at the user location (F), with an associated additional antenna, thus duplicating the GPS receiver equipment at the user location (F) in order to be able to eliminate the effect of equipment error.

6. A method according to claim 5,
characterized in that the position of the additional GPS receiver is determined
relative to the position of the second GPS receiver, the second and the
additional GPS receivers' antennae being arranged in such a manner that they
receive different interference conditions due to multiple-path propagation.

7. A method according to claim 6,
characterized in that the distance between the antennae of the two GPS
receivers at the user location (F) is selected in order to enable position errors
which are due to multiple-path propagation of the GPS signals to be identi-
fied, a corresponding space vector being calculated between the additional
GPS receiver and the second GPS receiver.

8. A method according to one of the preceding claims, wherein the position
determination is performed by means of DGPS,
characterized in that any ionospheric refraction of the GPS signals is cor-
rected by employing GPS receivers which work on two frequencies, both in
the monitor station (M) and in the user location (F).

9. A method according to one of the claims 1-7, wherein the position
determination is performed by means of DGPS,
characterized in that any ionospheric refraction of the GPS signals is identi-
fied by arranging the monitor station (M) and the reference station or
reference stations (R) in respective circular arcs which intersect each other in
such a manner that the user location (F) is located in the segment between the
said circular arcs.

10. A method according to claim 1, wherein the position determination has
to be performed in another datum than that to which GPS refers,
characterized in that a datum transformation is verified by means of integrity
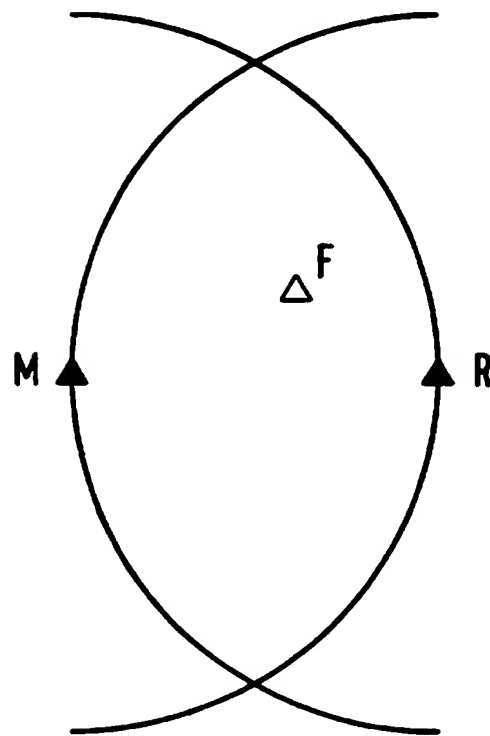monitoring, any error in the position thus also being determined in the second
datum.

Fig.1

2/2

Fig.2

INTERNATIONAL SEARCH REPORT

A. CLASSIFICATION OF SUBJECT MATTER

IPC6: G01S 5/14

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC6: G01S

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

SE,DK,FI,NO classes as above

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 5252982 A (FREI), 12 October 1993 (12.10.93), column 3, line 3 - line 65, figure 1 --	1-10
Y	GB 2213339 A (THE SECRETARY OF STATE FOR DEFENCE), 9 August 1989 (09.08.89), page 2, line 11 - line 32, figure 1, abstract --	1-10
A	WO 9414082 A1 (RUUS, JAN), 23 June 1994 (23.06.94), figure 1, abstract --	1-10
A	US 4812991 A (HATCH), 14 March 1989 (14.03.89), column 4, line 48 - column 5, line 23, figure 1 --	1-10

[X] Further documents are listed in the continuation of Box C.   [X] See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" erlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance: the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance: the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
13 June 1996	14 -06- 1996

Name and mailing address of the ISA/	Authorized officer
Swedish Patent Office Box 5055, S-102 42 STOCKHOLM Facsimile No. +46 8 666 02 86	Göran Magnusson Telephone No. +46 8 782 25 00

Form PCT/ISA/210 (second sheet) (July 1992)

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 5225842 A (BROWN ET AL), 6 June 1993 (06.06.93), abstract	1-10

--

INTERNATIONAL SEARCH REPORT
Information on patent family members

01/04/96

International application No.

PCT/NO 95/00239

Patent document cited in search report		Publication date	Patent family member(s)		Publication date
US-A-	5252982	12/10/93	DE-A- EP-A,A- JP-T- WO-A,A-	4026740 0497946 5503360 9203747	27/02/92 12/08/92 03/06/93 05/03/92
GB-A-	2213339	09/08/89	NONE		
WO-A1-	9414082	23/06/94	NONE		
US-A-	4812991	14/03/89	AU-B,B- AU-A- CA-A- DE-A- EP-A,A,B SE-T3- JP-T- WO-A,A-	590856 7435687 1268239 3776260 0264440 0264440 1501087 8706713	16/11/89 24/11/87 24/04/90 05/03/92 27/04/88 13/04/89 05/11/87
US-A-	5225842	06/06/93	AU-B- AU-A- AU-A- CA-A- EP-A,A,A JP-A-	663490 1499792 4089896 2066831 0512789 5180925	12/10/95 12/11/92 04/04/96 10/11/92 11/11/92 23/07/93